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ABSTRACT

Reported are three series of experiments analyzing the development of the visual function of infants. The first experimental series was aimed at the investigation of infants' reaction to moving objects. The second experimental series dealt with the analysis of the development of binocular vision in infants. The goal of the third series was to discover the boundaries and structure of the infant visual field. The fourth series was aimed at testing the mechanism of visual-vestibular interaction in infants. Principal conclusions from the findings suggest: (1) a genetically fixed mechanism that functions adequately from the first weeks of life is responsible for vestibulo-ocular responses (VOR) in infants; (2) vestibular afferentiation mainly triggers smooth eye movements; (3) VOR attain the most stable and smooth character in sleep, that is, when other sensory influences are minimal; (4) the ability to smooth compensatory eye movements and the ability to smooth foveal pursuit of moving objects develop heterochronously and are probably determined by different neurophysiological mechanisms; and (5) the effect of complex visual-vestibular afferentiation depends on age. The older the child, the stronger the influence of visual signals on the integral eye movement response. Theoretical implications of the findings are discussed. (RH)

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EYE MOVEMENTS AND VISUAL FUNCTION IN INFANCY: THE PROBLEM OF INTERDEPENDENCE*

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* ISSBD International Society for the Study of Behavioural Development (9th Biennial Meeting / Tokyo, Japan / July 12-16, 1987)

Dear colleagues,

It is an honour for me to be able to address this representative international forum. On the part of Soviet psychologists working on the problem of human development I would like to express my sincere gratitude to the organizers of this conference which is an important event theoretically as well as practically. I hope that my participation in this conference will be a contribution to the further development of the international cooperation of psychologists , necessary for the solution of the global problems humanity is facing.

Addressing our Japanese colleagues, I would like to say that this is my first visit to your country and, naturally, I will be glad to learn about your scientific and national traditions (as much as my short visit allows). We enjoyed working with Prof.Jutaka Matzuno who spent several weeks at our institute in Moscow. Our cooperation was productive, but quite naturally, it could not cover all possible aspects of cooperation of Soviet and Japanese psychologists on the problem of development. Therefore I would like to use this opportunity to acquaint all our colleagues (not only Japanese) with a few general problems of developmental psychology in our country, as well as with my own experimental findings.

Each new growing generation has to meet specific and very high standards set by the modern rate of the technological and social development of society. Therefore one of the main tasks of all sciences

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related to man is careful and thorough consideration of human ontogenesis in all its aspects - biological, social, psychological, physiological, genetic and others. It is this complex (or systemic, as we call it now) approach that will enable us to find adequate answers to urgent problems concerning the choice of effective methods of instruction and upbringing, rational utilisation of the organism's reserves, correct evaluation of the biological and social factors of development, optimal combination of physical, intellectual and moral development, etc.

At all stages of the development of Soviet psychological and pedagogical science childhood has been one of the central problems. World famous are the works of Makarenko whose theoretical and practical activity was an outstanding contribution to involving the "lost" younger generation in social life during the most difficult time in the history of our country. Nowadays when general education school is being reorganised, Makarenko's system is again in the focus of attention of Soviet educators.

In the history of Soviet psychology the problem of child development is closely connected with the names of Vygotsky, Ananiev, Rubinstein, Leontiev, Zaporozhetz, Galperin, Venguer. Each of these authors has developed his own specific understanding of the main factors and stages of development. I have no intention of reviewing the history of Soviet child psychology, therefore I will only mention that one of the central problems for many researchers is the relation between biological and social factors of development. It must be noted that there was a time in our history when genetic influence on human mental development was not recognized, which hindered construct-

ion of adequate models of ontogenesis. After genetics as a science was reinstated in its legitimate rights , it became possible to approach the problem of the relation between innate and acquired traits in ontogenesis more realistically.

Academician Belyaiev's controversial theory is of considerable interest in this respect. The conception rejects the view of man as nothing but a product of his social environment and emphasises the importance of inter-individual genetic variability and genetic uniqueness of the individual. At the same time the author excludes any possibility of opposing biological and social factors, insisting on the idea of a whole biosocial nature of man and on the understanding of the human brain as the organ of that biosocial organisation.

For a long time the child was predominantly viewed by Soviet psychologists as a solely social creature from the first minutes of his life, a creature whose mental development depends entirely on his environment. This approach, however, could not explain multiple facts concerning quick development of perceptual ability in infants at those developmental stages when social influences can hardly be called predominant. Therefore, it would be more reasonable to approach this problem from the point of view of the conception of structural and level determination of psychological phenomena formulated by B.F.Lomov who writes in this connection, "...sometimes the process of mental development is regarded one-sidedly (for instance, in its social aspect only). However, it is a many-sided process. In the course of development its determinants and systemic foundations change which is reflected in the formation of different systems of psychological traits at different stages of development. For instance,

at the earliest stages of ontogenesis development is determined by biological regularities which results in the formation of a certain system of traits. Even if social factors do come into play, their influence is mediated, they act outside the process of development. Later their significance increases until they become the leading determinant of development."

It is understandable that small children, just a few weeks or months old, are the best object for the investigation of innate forms of behaviour. The view that the baby is born with nothing but a limited set of elementary reflexes can hardly satisfy anyone nowadays. It is becoming increasingly evident that genetically determined forms of behaviour play a sufficiently important part not only in early ontogenesis, but throughout man's whole life. Therefore, discovering such basic forms of behaviour is especially valuable within the framework of the systems approach to the study of man.

In the main part of my talk I would like to tell you about the experiments carried out in the Laboratory of Perception of the Institute of Psychology of the USSR Academy of Sciences. The experiments dealt with the analysis of the development of the visual function in infants.

To a certain extent our experiments were based on the findings of Bauer and Fantz who proved that eye movements in infants are a good indicator of the child's preference of an object and his orientation towards particular features.

Our goal was two-fold. First, we aimed at discovering the specificity of the development of the basic types of eye movements in infants and the innate mechanisms responsible for those move-

ments. Second, on the basis of eye movements as an objective indicator of visual processes, we tried to form some notion of the peculiarities of the infant visual world. There was also the additional task of finding out the extent to which rigid links between different sensory systems manifest themselves in early stages of ontogenesis. In particular, we were interested in the links between the visual and the vestibular systems (this problem will be dealt with in connection with the last experimental series).

I am not going to dwell on the problems an experimenter has to overcome in working with babies - everybody must be aware of them. However, before I pass over to the description of the experiments, I would like to note that our naughty subjects were not all bad. We also found that babies in the first months of life are very honest and conscientious subjects. They are never sly or coquettish with the experimenter. They openly and attentively gaze at everything they like and just as openly turn away from what they do not like. It is this valuable quality of our subjects that helped us at the earliest and hardest stages of our work and gave us the necessary optimism.

The first experimental series was aimed at the investigation of infant reaction to moving objects. Evolutionary analysis shows that recognition of the movement factor is the most vital and therefore the earliest function of vision. Basic forms of eye movement activity (EMA) are determined by the need to attain that vital goal. Therefore, if we approach EMA from the evolutionary point of view, we are faced with basically one and the same question that could be asked in all its possible interpretations:
Is a few weeks old baby capable of responding to a moving stimulus?

To what extent does the eye movement correspond to the stimulation? What is the difference between EMA in infants and adults in these conditions? Are the innate motor forms predominant in eye movement responses of small babies? What are the most reliable parameters of movements?

These questions could not be answered without concrete experimental data. Though the first mention of the specific character of children's eye movements dates back as early as Dodge's works, progress in the objective analysis of the early ontogenesis of EMA was hindered by methodological difficulties. The few later works report isolated and often contradictory data. Therefore a cycle of experimental studies was carried out to obtain more detailed data on the early ontogenesis of EMA with the aim of answering, as far as we can, the above mentioned questions.

The experiments were carried out in two Moscow children's homes. The subjects were babies aged from 2 to 16 weeks. The lower age limit was determined by the actual age of the children, the upper was chosen because the first four months of the child's life are characterized by specific motor abilities and absense of somatic sensorimotor coordination.

The electrooculographic method was used to register eye movements (Figure 1). The method allows recording of eye movements with the amplitude of 1^{o}. Besides, it can be used in natural conditions of visual activity and excludes any unpleasant sensations. The experimental procedure was organized in the following way. The baby was placed on his back in a cot. A specially designed headrest supported the child's head from the back restricting its movements and

at the same time allowing registration of head movements to right or left. Before the experiment the child was tightly swaddled to restrict the motor responses of arms and legs. Each experiment lasted 10 to 15 minutes.

Above the child's head at a distance of 40 cm from the cyclopean eye a stimulus was moved back and forth in the horisontal plane (with the help of a special electromechanical device). (Figures 2, 3). The size of the object was 10°, its velocity - 12°/sec. and 24°/sec. The choice of velocities was determined by the following considerations: 1) the given velocities are within the optimal tracing range of adult subjects; 2) objects moving at the speed of 12 to 25°/sec. are the most likely to trigger optomotor responses in animals.

A meaningful stimulus was used in this experimental series, because, as preliminary data showed, a meaningful stimulus, such as a face, for instance, triggers tracing two times more often than indifferent stimuli, such as lamps, geometrical figures of different colours or animal figures.

The results of the experiment are as follows.

Tracing of a moving stimulus can be observed in the youngest subjects aged two weeks. At the earliest stages of postnatal development of the eye movement function pursuit eye movements have the character of a succession of saccades separated by fixation pauses. Throughout the process of tracing each subject displays a certain stability of the elements that determine the character of the record, such as steepness of saccade slope, amplitude, length of inter-saccade intervals.

Saccadic (step-to-step) tracing is gradually replaced by smooth pursuit which can be observed in 10-week-old babies.(Figure 4). The objective indicator of the transition to smooth pursuit is reduction of saccade amplitude and of length of the inter-saccadic interval (Figure 5).

Tracing of a moving object improves rapidly. Its development can be represented in stages.

Stage I corresponds to the age of 2 to 4 weeks. At this stage the eyes trace the moving object, tracing is saccadic and occurs during a very short period (30 to 60 sec.).

Stage II - age 8 to 14 weeks. Tracing retains the step-to-step character. The child's eyes are "captured" by the object. Tracing has the character of an automatic motor action.

Stage III begins after 16 weeks when smooth pursuit of the stimulus becomes possible and the automatic action of Stage II disappears.

The saccade is the predominant form of EMA in infants of up to 16 weeks of age. Our data as well as the findings of Aslin and Salapatek allow us to conclude that the saccade mechanism is innate. It emerges in the process of embryonic development and starts to function from the moment of birth. The biological function of quick saccades in the behaviour of higher animals and humans is vitally important. They are responsible for the necessary speed of response, an essential component of which is selective phoveal-isation of the most significant objects. One of the principles of systemogenesis that determines the development of human EMA is priority in the functional provision of the most vital biological systems. The innate saccade mechanism realizes the earliest

ocular responses of the newborn child. Inclusion of the smooth form of EMA evidently requires a more complex sensorimotor coordination.

The second experimental series dealt with the analysis of the development of binocular vision in infants. Investigation of binocular vision is inseparable from the problem of the perception of the third dimension - depth, in other words, from the problem of stereoscopic vision. Thorough investigation of the mechanisms of stereoscopic vision on the basis of the systems approach requires: a) analysing those features of the objective world that are reflected in and constitute the main content of the given form of perception; b) discovering the functional structure of the system of stereoscopic vision, its components and relations between them; c) investigating the development and formation of the mechanisms responsible for the perception of depth, establishing the relationship between innate and acquired components of this function.

The problem of the perception of the third dimension can be traced throughout the history of modern philosophy and psychology. It has been a kind of touchstone for different conceptual systems. Berkly's formula, "initially the world appears flat to us", was supported by the sensualists and reached its ultimate expression in Kondilliak's famous allegorical statue that gradually passed from flat to stereoscopic vision thanks to the accumulation of life experience. In Kondilliak's wake, all adherents of the empirical school in psychology relate perception of depth to the subject's experience assuming that flat retinal image cannot give us any information about the third dimension. Helmholtz treats the

problem in a similar way in his philosophic and physiological theory. Unlike assosiative psychology, Gestalt theory with its roots in phenomenalist philosophy, does not link perception of depth to experience, but to the subject's inner organisation. With the help of the categorical system of Gestalt theory (the notions of pregnant form, isomorphism, field and force lines, transformation and transposition, symmetry and balance, organisation) the act of stereoscopic vision can be represented as the observer's reconstruction of a whole, complete form on the basis of fragments of the retinal image. In this context it is not essential whether the target of observation is a three-dimensional physical object or its flat outline. The decisive factor is not the peculiarities of outside stimulation, but the inherent laws of the Gestalt.

Gestalt theory was instrumental in the development of the notion of the derivative character of stereoeffect. According to this view, the effect appears after a stereoscopic image of the object has been formed. However, more detailed tachistoscope studies show that stereoeffect precedes object vision. Vagueness of the stimulus does not disturb stereopsys, which means that assessment of depth does not depend on object perception, but on the contrary, object vision is formed on the basis of initial stereopsys mechanisms.

Thus the postulate of the initial flatness of the world which has its adherents to this day, appears very questionable. Two-dimensional morphology of the retina does not necessarily mean that immediate perception of space is two-dimensional. Following the logic of Berkley and Kondilliak, we would have to admit that initially we perceive the world as being 2cm in size because such is the

size of the retina. I do not think anybody will seriously support that statement.

Summing up the findings of modern psychophysiology of vision, I.Rock opposes the long-living notion of the flat picture of the world by suggesting the idea of innate three-dimensional perception. In our opinion, this thesis is well-grounded. The baby is born with a motor apparatus allowing it to move in three dimensions. Similarly, it must possess sensory mechanisms ensuring its orientation in three-dimensional space - rough and imperfect at first, but adequate in principle.

This assumption can be substantiated by two groups of facts. First, ontogenetic material collected during the past decade testifies that infants display adequate optomotor responses to changes in distance to the object. Second, it is by now a well-established fact that the primary visual cortex has neurons sensitive to binocular disparity.

Proceding from the above, it can be assumed that infants in the first weeks of life possess rapidly developing mechanisms responsible for elementary orientation in the third dimension. It must be noted in this connection that psychologists are inclined to confuse two questions: How and what to does the infant respond? and What does the infant subjectively see? We do not think the second question would be appropriate in this context.

As it was mentioned above, binocular disparity is the main factor determining perception of depth in adults. However, the conditions of normal stereoscopic vision in real environment, i. e. the conditions in which the eye moves constantly from one object to another, require a mobile and fine mechanism assuring location of the

object in Panum's zone. This disparity regulating mechanism is vergent eye movements. It has been discovered that vergent movements are determined by the direction of disparity. Also, as many researchers emphasize, convergence angle and proprioceptive sygnals from the eye muscles are essential for the evaluation of object depth. Subjective perception of depth can be modified by means of artificially changing (with the help of prisms) the direction of vergent movements while the value of disparity remains constant. This points to the existence of a whole vergent-disparity system in depth perception.

In other words, this suggests a method of obtaining objective data on the development of binocular vision in early ontogenesis. We must analyse the specificity of vergent eye movements as one of the essential components of depth perception. The data available are isolated and very contradictory. Therefore a sufficiently systematic study of vergent movements in different age groups was required.

The experiments differed from the previous series in that horizontal movements of the left and right eyes were recorded separately. The children were divided into 5 age groups. The first included children aged from 4 to 5 weeks, the second - from 7 to 8 weeks, the third and the fourth - from 12 to 16 weeks, the fifth- from 31 to 33 weeks. On the whole 20 children and 4 adults took part in the experiments.

The experimental procedure was organized in the following way; (~~Figure 6~~).

The experimental object was placed above the child's head at a distance of 45 cm from his eyes along the gaze line of the cyclopean eye. The object could move along a straight line parallel with or perpendicular to the child's face. Geometrical figures of different colours and pictures of human faces served as experimental objects.

The goal of the first variant of the experiments was to study the development of vergent eye movements in different ages in the conditions when an attractive object moved towards or away from the child along the cyclopean visual axis. Weak binocular conjugation displayed by the youngest subjects in these conditions suggests that the mechanism of conjugated eye movement control is not developed at this age at all. To test that hypothesis, in the second variant of the experiments, version eye movements of each eye (i.e. conjugated side turns) triggered by the frontal movement of the objects were recorded separately. In the third variant of the experiments which repeated the conditions of the second, one eye of the subject was alternately covered with a non-transparent screen. (F E) The latter condition revealed that there are no rigid innate programmes realizing conjugation of eye movements in response to monocular stimulation. In the fourth variant of the experiments , as different from the first, the stimulus did not move along the cyclopean axis, but along the visual axis of each eye in turn. In such conditions the requirements to the motor responses of each eye were essentially different. (Fig. 7).

The principal results of this experimental series are as follows:

- adequate vergent responses to objects approaching or moving away can be observed in infants in the first weeks of life and are determined by genetically fixed mechanisms;
- innate forms of vergent eye movements possess great plasticity thanks to which they improve rapidly at the age of 1 to 5 months in the process of learning and approximate the adult level of accuracy;
- mechanisms responsible for binocular coordination in version and vergent eye movements develop and improve parallelly. At the same time, development of coordinated version movements keeps slightly ahead of the development of coordinated vergent movements;
- low accuracy of vergent movements in infants of 3-4 months of age correlates with poor development of phoveal vision. It is possible that the initial level of vergent control at this age is determined by the activation of the parafoveal retinal zones and, accordingly, of the structures of the second visual subsystem , and also, by the innate mechanisms of the accomodative-vergent subsystem that precedes the development of the more subtle vergent-disparate (binocular)system.

The goal of the third experimental series was to discover the boundaries and the structure of infant visual field.

The results of experiments with point stimuli, inadequate for infants, led to the belief that the visual field of newborns and babies in the first weeks of life is very small (about 5 - 10°).

This view, however, comes into conflict with the later data as well as with modern neurophysiological conceptions. It must also be born in mind, that development of eye movements is inseparable from their retinal (peripheral) afferentation. If we accept the idea that the infant visual field is initially small, we cannot but wonder how a baby performs saccades with amplitudes considerably exceeding 5^{o}. These and a few other considerations motivated another experimental cycle aimed at discovering actual functional abilities of peripheral vision in infants aged from 2-3 weeks to 6 months in different stimulation conditions.

In the first phase of the investigation we analysed infant ocular responses to the presentation of various stimuli, such as miniature lamps, dolls, toys etc. and also moving objects of different sizes, in different parts of the visual field. The experiments showed that in infant studies point stimuli, such as lamps, are much less effective than moving objects, especially when the latter have considerable angle dimensions and a high degree of contrast. The experiments also showed that the visual field and, accordingly, the retina of the infant, initially have an anisotropic structure. The centre and the periphery of the field as well as the periphery of different eccentricities, are characterized by different sensitivity to different parameters of stimulation. Adequate ocular response to large moving objects could be observed in the youngest children if objects appeared in the periphery of the visual field with the eccentricity of $55-60^{o}$.

The second phase was aimed at testing infant ability to dis-

criminate between simple geometric figures which were presented by means of a tachistoscope in different peripheral zones of the visual field. It was discovered that children are capable of such discrimination already in the first weeks of life; this ability manifests itself in preferential ocular responses to different forms.

The third phase of the investigation resulted in the discovery of a pronounced directional assymetry in the structure of infant visual field. This manifested itself in the appearance of opto-kinetic nystagmus in response to the temporal-nasal movement of contrasting strips (in conditions of monocular presentation) and absense of OKN if the stripes moved in the opposite direction. The finding reflects the specific part played by peripheral vision in the detection of movement.

The results of the above experimental series could be summed up as follows:

1. The visual field begins to function as a whole structural formation at the earliest stages of postnatal ontogenesis.
2. Central and peripheral vision in infants develop heterochronously: the first months of life are the time of predominant development of peripheral vision.
3. As a consequence of the above mentioned heterochroneity, the ability to general orientation in space (realized by peripheral vision) presedes the ability to detailed analysis.
4. The infant forms a whole visual picture of his environment on the basis of close interaction of central and peripheral vision.

The fourth experimental series was aimed at testing the mechan-

ism of visual-vestibular interaction in infants.

The least studied aspects of vestibulo-visual interaction are above all the problems pertaining to the mutual genesis of the two systems in general and their functioning in early human ontogenesis in particular. To what extent are vestibular and ocular responses determined by innate mechanisms and which components of these responses are formed after birth? How do these responses change during the child's first weeks and months of life? What is the relative contribution of labyrinth and retinal afferents to the conjugated work of the vestibular and visual systems at different stages of early postnatal ontogenesis.

With the aim of answering these and some other questions, at least in the most general way, we undertook an experimental study in infants of 2 to 16 weeks of age. Natural stimulation of the labyrinth was produced by means of rotating the subjects sinusoidally around the axis parallel to the longitudinal axis of the body. During the experiments the subjects were placed on their backs in a specially designed cradle (Figure 2). The hinges that fastened it to a stationary base allowed its rotation around the horizontal axis within the range of $\pm$ 40°. With the help of elastic belts the child was fixed in a depression of thick foam which tightly fitted the child's body preventing side shifts. Oscilation frequency varied from 0.25 to 2 Hertz. The cradle with the baby was placed in a cot.

Experimental conditions permitted visual stimulation alongside vestibular stimulation. For that purpose a test-object was placed above the child's head at a distance of 20-25 cm from the bridge of his nose. The test-object was a rectangular semi-transparent

white-and-black striped screen. The stripes were oriented along the length of the child's body; the width of both black and white stripes was about 6^{o}, the overall angle dimensions of the visible field - 75×90^{o}. The striped test-object was in one case fixed to the side posts of the cot (in the horizontal plane), in the other case - to the vertical posts of the cradle. In the first case the test-object remained stationary when the cradle moved and, consequently, in the child's visual field it moved in the direction opposite to that of rotation. In these conditions ocular responses in an alert child were triggered by the dual, but conjugated visual-vestibular stimulation. In the second case the test-object moved together with the cradle and therefore it remained stationary in the child's visual field despite vestibular signals that the cradle was turning. In this way a conflict was created between labyrinth and retinal afferentation of eye movements. To exclude environmental influences, the cradle was screened on four sides with white material.

The electrooculographic method was used to record horizontal eye movements.

Results. a) Vestibulo-ocular responses in sleep.

At the initial stage of sleep retinal afferentation is absent (or extremely weak) and rapid eye movements typical of the later phases have not appeared yet. It might be expected that in such conditions labyrinth stimulation is likely to trigger the ocular response proper (i.e. independent of other factors). Binocular and monocular records of sleeping or drowsy babies (Figure 8) show that this is really so.

All records display one important peculiarity: ocular responses to natural labyrinth stimulation in sleeping infants have as a rule a smooth tonic character throughout the whole range of the studied frequencies of the sinusoidal movement of the cradle.

Since oculomotor responses are rigidly determined in these conditions, the results of this experimental series can be used to find out the degree of inertia of the processes taking place in the vestibulo-ocular afferent- efferent system. The value of phase shift between acceleration peak and maximum deviation of the eye could be regarded as the inertia index. The record (Figure 8g) shows that the eyes reach peak position before the cradle turns to the extreme antiphase position.

b) Compensatory and anticompensatory eye movements.

Unlike compensatory turns that have a smooth character, anticompensatory movements are realized by means of saccades. These saccades, in resistance to vestibular influences, achieve a quick visual capture of the objects as the head turns in their direction. Anticompensatory saccades are an indicator of the subject's activity, they are typical of the state of alertness and are absent in sleeping infants.

The proportion of saccades in the sum total of vestibulo - ocular responses in children increases dramatically with age. In children of up to 2 months of age vestibular afferentation remains the leading determinant of eye movement activity even in the state of alertness and in the presence of visual stimulation. Records made of 3-4 month old children look different.(Figure 9 a-g).

The sinusoid is considerably disturbed by high amplitude saccades in combination with smaller differently directed saccades that are an indicator of active scrutiny of the test-object.

c) Eye movement responses in conditions of conjugated visual-vestibular stimulation.

Conjugated visual-vestibular stimulation was produced when the alert child was looking at the test-object (N 1) (Figure 7) that remained stationary when the cradle was rocked. The many records made in such conditions exhibit characteristic "flattening" of the upward and downward slopes of the sinusoid and sharpening of the peaks, oscillations approximate triangular shape (Figure 10,a). This characteristic phenomenon is more typical of the youngest children. In infants aged over 2 months, as it was mentioned in section b), the rhythm of oscillations was considerably masked by voluntary eye movement activity of the subject. As obvious changes in the sinusoidal shape of the records show, the presence of a visual stimulus in the visual field affects vestibulo-ocular responses from the first month of life.

d) Ocular responses in conditions of conflicting visual-vestibular stimulation.

Responses of this type occurred when test-object N 2 moved together with the cradle (Figure 7) which resulted in the stabilisation of the gaze despite labyrinth afferentation. Records made in such conditions approximate trapezoidal shape (Figure 10,b). This transformation of the sinusoid can be accounted for in the following way: when the direction of cradle movement changes, the infant's

gaze, in resistance to vestibular stimulation, continues to fix a certain zone of the test-object (point 1). As the record shows, vestibular stimulation is capable of producing a gaze shift, but for a certain time visual stimulation remains predominant which is reflected in a plateau 1-2. In point 2 vestibular stimulation prevails and the eyes quickly move to the opposite side of the test-object (pont 3). After that the whole cycle is repeated with the cycle length roughly equalling half period of oscillations.

As multiple records show, slow smooth components prevail in compensatory eye movements of vestibular origin in infants. At the same time, as our own experiments and other data prove, in infants in the first weeks of life it is very difficult to record smooth pursuit of isolated stimuli moving evenly in the visual field. A stimulus of considerable angle dimensions (about 12°) moving within a limited range of velocities could produce a few smooth inclusions in the oculogram in a few children. On the whole, however, infant pursuit of moving stimuli is saccadic which is reflected in a characteristic step-to-step oculogram.

Analysis of these two groups of facts allows us to question the popular view that smooth compensatory eye movements (vestibularly afferented), smooth components of nystagmus and smooth pursuit of moving objects are realized by a common neurophysiological mechanism. Heterochronous development of the ability to smooth vestibular compensation and of the ability to smooth pursuit points to the difference rather than sameness of their mechanisms. As to optokinetic nystagmus (OKN), it can be triggered in a child of 1-2

months of age just as easily as compensatory eye movements (by means of moving an endless striped band occupying a greater part of the visual field). Besides, the smoothness of the slow components of OKN is just as pronounced in infants as in adults. Evidently, the smoothness of nystagmic eye movements is of vestibular origin in this case and is determined by the activation of secondary vestibular neurons on which labyrinth and retinal afferents converge. The similarity between the smooth component of OKN and smooth compensatory eye movements is determined by their common vestibular origin.

On the other hand, the mechanism of smooth phoveal pursuit of moving stimuli cannot be identified with the two above mechanisms.

Evidently, we can make a conclusion that different mechanisms are responsible for smooth pursuit and for smooth compensatory eye movements (irrespective of whether they are triggered by vestibular or optokinetic stimulation). Smooth pursuit is a later phylogenetic formation that fully develops in primates. This function is closely related to the improvement of binocular phoveal vision. In infants the formation of the macular region of the retina is not completed until 16 weeks after birth. Approximately at the same age pursuit of moving stimuli acquires a smooth character. Thus, heterochronous appearance in early human ontogenesis of the ability to smooth vestibular compensation and of the ability to smooth phoveal pursuit reflects the specificity of the development of two different subsystems.

Principal conclusions from this experimental series.

1. A genetically fixed mechanism that functions adequately from the first weeks of life is responsible for vestibulo-ocular responses (VOR) in infants.
2. Vestibular afferentation mainly triggers smooth eye movements.
3. VOR have the most stable and smooth character in sleep, i.e. when other sensory influences are minimal.
4. The ability to smooth compensatory eye movements and the ability to smooth phoveal pursuit of moving objects develop heterochronously and are in all probability determined by different neurophysiological mechanisms.
5. The effect of complex visual-vestibular afferentation depends on age: the older the child, the stronger the influence of visual signals on the integral eye movement response.

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Theoretical results of the above experimental studies can be summed up as follows.

The problem of the relationship between the innate and the acquired (through learning) in the functioning of the visual system is closely related to the problem of the general theory of vision. For a long time psychologists used to believe that the infant visual world is chaotic, the role of the innate visual functions - minimal and that of perception training - all important. As modern scientific progress shows, such views were caused by the lack of knowledge of fine neurophysiological mechanisms of vision, by

the underestimation of evolutionary factors, by the lack of reliable data pertaining to early ontogenesis of sensori-perceptual functions.

Nowadays the situation is essentially different. Multiple neurophysiological, psychological and ontogenetic studies (including the research carried out by myself together with a group of colleagues) show that the baby is born with certain genetically fixed mechanisms that determine the peculiarities of his visually controlled behaviour in the first months of life. Without such basic mechanisms training of the visual system would have been impossible.

Like any other system of the organism, the visual system combines rigidly fixed links formed in the course of the evolution of the eye of vertebrates , and flexible plastic links ensuring adaptation to changing environment. In the process of phylo- and ontogenesis rigid links retain their importance: any stage in development presupposes close interaction of rigid and flexible elements of the system. However, in spite of the extraordinary plasticity of the system as a whole, variability of the functioning of flexible elements has certain limits.

Another principal problem is the genetic priority and interaction of central (phoveal, macular) and peripheral vision. For a long time this problem was consistently ignored both by psychologists and by physiologists. All popular theories of vision - from Helmholtz's physiological optics to the Hubel - Viesel hypothesis - are actually founded on the mechanism of

focal vision and ignore retinal anisotropy. At the same time, it is becoming increasingly obvious that a whole picture of the world can emerge only as a result of a complex and so far little studied interaction of central and peripheral vision.

Construction of such a picture as well as perception of complex objects starts with general orientation in space and rough preliminary assessment of the situation as a whole which is followed by discrimination and analysis of details. Bekhenov who attributed a great importance to the problem of perception genesis, wrote, "In all his encounters with the outside world the child is subject not to isolated outside influences, but to groups or series or, generally, sum totals of such influences in the form of outside environment." At present similar views are being maintained by J.Gibson and his adherents. In the Soviet Union this theoretical approach is represented by the conception of perception phases developed in the works of B.G.Ananiev and B.F.Lomov.

A third principal problem concerns the role of eye movements in the genesis of visual functions. The psychological content of the problem was to a certain extent influenced by Hebb's hypothetical model based on the concept of "cell ensembles" activated in succession and united by means of eye movements. But the given model denies the infomativity of peripheral vision in principle, which is incompatible with more up-to-date neurophysiological ideas and with the results of onto-/phylogenetic studies which show that extraphoveal analysis of the form precedes phoveal analysis. Besides, if we accept the idea of element-to-element construction of the image (like a mosaic picture), we are inevitably faced with

the following antinomy: if the image is created by means of successive fixation of elements, it is not clear how the necessary elements are selected when the image is absent; if emergence of the image precedes gaze shifts, we will have to admit that eye movements are aimless, at least in relation to image construction.

Therefore it would be more natural to suppose that general assessment of the situation and its detailed analysis are two sides of the whole process of image formation with the first genetically preceding the second. As a result of this unity, detailed analysis (discrimination of local features with the help of eye movements) acquires initial organisation based on the innate ability to contrast discrimination as well as the ability to rough discrimination of form, size, and distance of objects. It is as if the description of elements superimposes on the initial rough pattern.

The fourth problem - that of visual perception of space and the relationship between flat and stereoscopic vision - dates back a very long time. Berkley's formula "initially the world appears flat to us" had a magic influence on all further development of phylosophic and psychological ideas. It took about 300 years to replace (with sufficient confidence) Berkley's formula with the idea that visible space is initially three-dimensional.

In all probability, mechanisms responsible for perception of space and of spatial relations are inseparable from the organism's motor functions. Following in Sechenov's tradition, Soviet psychologists provided ample proof for the thesis of the inseparable unity of perception and motion. This is their great contribution. In all probability, the clue to understanding the genesis of depth percept-

ion lies somewhere there. A newborn child moves in three-dimensional space and possesses the necessary sensory abilities. Initial evaluation of depth (rough and primitive) correlates with the primitive motor forms and are polymodal by nature.

Our study of vergent eye movements showed that infants possess innate sensorimotor mechanisms that enable him to respond adequately to an object moving towards him or in the opposite direction. A sophisticated system of visual evaluation of space develops in ontogenesis on the basis of these mechanisms.

Our approach to the fifth problem - that of the relationship between dynamic and static stimulation - also conflicts with the traditional view. The firm belief that visual perception of stasis is prior to that of dynamics, resulted from standard laboratory procedures involving presentation of static stimuli. However, basic neurophysiological mechanisms of vision are better adjusted to the recognition of the movement factor. Therefore it is no wonder that Harline's discoveries that opened a new epoch in neurophysiology, were made on moving stimuli.

I can well understand the reason why Philip Salapatek, an extremely competent American researcher, finishes his section of a book about child perception with a kind of apology because, in the tradition of the classical laboratory experiment, he used stationary flat objects in his experiments with infants, though he realized that such conditions were incompatible with those of the real training of the visual system. In our experiments moving stimuli and three-dimensional objects prevailed. It was in those conditions that the most interesting new data were obtained. Comparative

analysis of data obtained in infants in static and dynamic conditions allows us to assert that moving objects play a decisive part at the initial stages of the training of the visual system.

Finally, our data concerning vestibular influences on eye movement behaviour point to the existence of rigid innate links between the visual and vestibular systems which later serve as a basis for the development of complex forms of the interaction of these systems.

In conclusion I would like to thank my Japanese colleagues again for the invitation to this conference, and all those present - for their patient attention.